CHARACTERIZING GROUNDWATER QUALITY IN KENTUCKY: FROM SITE SELECTION TO PUBLISHED INFORMATION

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Biographical Sketch of Authors

Stephen Fisher is a hydrogeochemist in the Water Resources Section, Kentucky Geological Survey. His primary interests are the geochemical controls on groundwater chemistry, design of groundwater monitoring networks, and delineation of groundwater flow paths. Peter Goodmann has worked for the Department for Environmental Protection for 9 years, and has been manager of the Division of Water's Groundwater Branch for 6 years. He is responsible for overseeing the implementation of Kentucky's wellhead protection program, groundwater protection program, water-well driller certification program and well construction standards, karst research and mapping projects, groundwater data collection and compilation including the statewide ambient groundwater monitoring, and developing groundwater quality status reports.

Abstract

The Kentucky Geological Survey (KGS) and the Kentucky Division of Water (DOW) are collaborating to produce maps and statistical summaries of groundwater quality statewide, within physiographic regions, and within major watersheds. The results are distributed to citizens, water-resource planners and managers, regulatory agencies, researchers, and educational programs. In the process of producing these maps and summaries, KGS and DOW must resolve at the statewide level many of the issues addressed by the National Water Quality Monitoring Council at the national and international levels.

The major challenges in gathering new groundwater-quality data and converting existing data records to useful information are: (1) selecting representative sites for new sampling and deciding which parameters to measure, (2) combining existing water-quality records from databases that were designed for different purposes by different agencies, (3) reconciling diverse analytical methods, analyte names, detection limits, and documentation levels, (4) graphically presenting statistical summaries and choosing appropriate concentration ranges for map displays, and ultimately (5) developing web-based databases to enable the public to search the records and display the results.

To date, pH, nitrate-nitrogen, atrazine, fluoride, arsenic, and water hardness have been summarized and mapped. We are continuing to describe and summarize constituents that indicate groundwater source and flow path, record the effects of nonpoint-source contamination on groundwater resources, and limit the suitability of groundwater for various uses throughout the state. This information can be used to develop groundwater standards, refine the monitoring program, and make informed decisions about best management practices to protect groundwater resources.

Groundwater Use in Kentucky

Groundwater is extensively used throughout Kentucky. According to recent DOW estimates, approximately 500,000 persons depend on groundwater from wells and springs to supply individual households, and 254 public water systems use groundwater to supply 1,292,271 people. An additional 226 million gallons of groundwater are used daily by commercial and industrial operations, farmers and ranchers, mining operations, and thermoelectric power generators. Groundwater also provides base flow to rivers, streams, and lakes, and therefore sustains important ecosystems and contributes to recreational uses such as fishing, boating, and swimming, particularly during droughts.

Groundwater in Kentucky will continue to be important because replacing groundwater supplies with surface water is typically not economical or practical. Because of the importance of groundwater to Kentucky and the difficulty of remediating contaminated groundwater systems, it is critical that the current quality of groundwater resources be determined and protected.

The Kentucky Interagency Groundwater Monitoring Network

Systematic efforts to summarize groundwater quality and make that information widely available began only recently. Legislative action by the Kentucky General Assembly, as well as decisions by KGS, DOW, and the Kentucky Water Resources Research Institute, led to the formation of the Kentucky Interagency Groundwater Monitoring Network and the current collaboration between KGS and DOW. The Kentucky Groundwater Data Repository, housed and maintained by KGS, was created in 1990 by the Kentucky General Assembly to archive groundwater data collected by State and Federal agencies, universities, and other researchers. The 1994 Kentucky General Assembly appropriated funds for DOW to establish and maintain an ambient groundwater monitoring program.

The Kentucky Interagency Groundwater Monitoring Network developed from the realization that there was not sufficient information available to make informed decisions regarding groundwater management and protection. Following the creation of a Groundwater Consensus Committee in 1993 by the secretary of the Kentucky Natural Resources and Environmental Protection Cabinet, a bill was drafted to establish a long-term groundwater monitoring network and an advisory committee on groundwater issues. The proposed legislation did not pass then, but interest in groundwater persisted. An ad hoc advisory committee, led by the director of the Kentucky Water Resources Research Institute, met throughout 1995 and 1996 and published a framework for the Kentucky Groundwater Monitoring Network (Interagency Technical Advisory Committee on Groundwater, 1996). In 1998, the Kentucky legislature directed KGS to establish a groundwater monitoring network and also established an Interagency Technical Advisory Committee on Groundwater (ITAC: Table 1) to assist KGS in developing, coordinating, and implementing the network. The goals of the Kentucky Interagency Groundwater Monitoring Network are to collect groundwater data, characterize groundwater quality, distribute the resulting information, improve coordination among agencies that monitor groundwater, and facilitate electronic transfer of groundwater data.

Table 1. Agencies comprising the Interagency Technical Advisory Committee on Groundwater.

Kentucky Department for Environmental Protection
Kentucky Department for Natural Resources
Kentucky Department for Surface Mining Reclamation and Enforcement
Kentucky Department of Mines and Minerals
Kentucky Division of Conservation
Kentucky Division of Environmental Health and Community Safety
Kentucky Division of Forestry
Kentucky Division of Pesticide Regulation
Kentucky Division of Waste Management
Kentucky Division of Water
Kentucky Geological Survey
U.S. Geological Survey
University of Kentucky College of Agriculture
University of Kentucky Water Resources Research Institute

Mapping and Summarizing Groundwater Quality Data

Collecting groundwater quality data and transforming database records into useful information involves (1) selecting sites, collecting and analyzing samples, (2) storing and extracting records from a database, (3) statistically summarizing water quality, and (4) mapping sample sites and concentration ranges.

Site Selection, Sample Collection and Analysis

The DOW groundwater monitoring program has two components: a regular sampling of the same 100 wells and springs quarterly each year, and an expanded monitoring program that coordinates with Kentucky's Watershed Management Framework (Kentucky Division of Water, 1997). The Management Framework groups the state's 13 major river basins into 5 Basin Management Units (BMUs), and focuses surface-water sampling on a single BMU for one year. The Management Framework then rotates the surface-water sampling to the next BMU, taking 5 years to complete the cycle. The expanded groundwater monitoring program selects 30 new sites in the BMU in which surface-water sampling is occurring, and samples them quarterly for a 1-year period. The following year, both surface-water sampling and groundwater monitoring shift to the next BMU.

The groundwater monitoring program is intended to represent the various physiographic, geologic, land-use, and demographic settings in Kentucky. Existing wells and springs are sampled because resource limitations preclude drilling new wells in selected locations. Sites for expanded monitoring are selected as follows.

1. Each 7.5-minute quadrangle in the BMU is assigned a number, and 30 numbers are drawn at random. Quadrangles in which other groundwater monitoring is being performed are not considered. If there are no suitable wells or springs in the selected quadrangle, an adjacent quadrangle is selected.

2. Within each selected quadrangle, potential sample sites are prioritized according to use, condition, and accessibility. Large springs are preferred over wells because such springs collect water from large basin areas and are more sensitive to nonpoint-source pollution. Public wells or nonregulated public springs used for domestic purposes are chosen over private wells or wells used for livestock or irrigation. Springs protected from local surface runoff and properly constructed wells are preferred to avoid sample contamination. Readily accessible springs and wells are selected over sites in remote locations or sites with limited access.

3. Final site selections are made only after field inspection to ensure that seasonal monitoring is feasible and after obtaining permission from owners.

Samples are collected according to an approved QA/QC plan and analyzed according to EPA-approved methods for inorganic solutes, nutrients, pesticides, volatile organic compounds, and polycyclic aromatic hydrocarbons.

Data Storage and Extraction

Site descriptions, sample information, and analytical results are entered into the DOW groundwater database and are copied to the Kentucky Groundwater Data Repository at KGS, which also contains analytical results from groundwater studies by the U.S. Geological Survey, U.S. Environmental Protection Agency, U.S. Department of Energy, University of Kentucky researchers, and other researchers. Combining groundwater data from various agencies provides better geographic coverage of the state and a more extensive database. The disadvantage, however, is a lack of uniformity in analyte names, analytical methods, detection limits, concentration units, and reasons for sampling a particular site. For example, four different analyte names are used for ammonia, and organic constituents commonly are listed under even more individual names. Detection limits reflect changes in instrumentation and level of concern: arsenic analyses have 13 different detection limits, ranging from 0.052 to 0.0002 mg/L. Some samples were collected from wells installed to test for underground storage tank leaks, but this purpose is not obvious from the information recorded. Inevitably, there are errors in transferring data from original reports to the database. The result is that database queries must be carefully constructed and the records retrieved from the database must be carefully examined before useful information can be produced from the data.

Statistical Summaries

Summarizing hundreds to thousands of analytical results in a manner that is clear and useful to a general audience presents additional challenges. It is well known that statistical measures such as mean and standard deviation commonly do not accurately represent the distribution of water-quality data (e.g., Helsel and Hirsch, 1992). KGS and DOW use nonparametric statistical measures to summarize analyte concentrations. The combination of tabular listings of quartile (minimum, first quartile, median, third quartile, and maximum) values and graphic displays (normal probability plots and box-and-whisker diagrams) seems to work well for a general audience. For example, Table 2 and Figures 1 through 4 summarize 3,559 pH measurements at 682 sites in BMU 3 (9,560 square miles; watersheds of the Upper and Lower Cumberland, Tennessee, and Mississippi Rivers) and BMU 4 (11,410 square miles; watersheds of the Green and Tradewater Rivers).

In BMU 4, pH values are much more tightly clustered around the median than in BMU 3. The interquartile range (IQR, difference between the third quartile value and the first quartile value, representing the middle 50 percent of the data) for BMU 4 is only 0.3 pH units, whereas the range for BMU 3 is 1.1 pH units (Table 2). The median pH values are also significantly different (6.9 in BMU 3 versus 7.5 in BMU 4).

	BMU 3	BMU 4
Number of measurements	2550	1009
Number of sites	434	248
Maximum	9.5	12.4
3rd quartile	7.4	7.7
Median	6.9	7.5
1st quartile	6.3	7.4
Minimum	1.7	0

Table 2. Summary of pH data for groundwater samples from Basin Management Units 3 and 4.

Figures 1 and 2 show the distribution of pH values and compare the observed distribution to that of a normally distributed population (straight lines in each plot). The difference in data distribution is obvious. Approximately 95 percent of the values from BMU 3 follow a normal distribution (from about 5.5 to 8.5), with a significant tail of low pH values (Fig. 1). Approximately 80 percent of samples from BMU 4 follow a normal distribution (between about 7 and 8), with tails to both higher and lower values (Fig. 2).

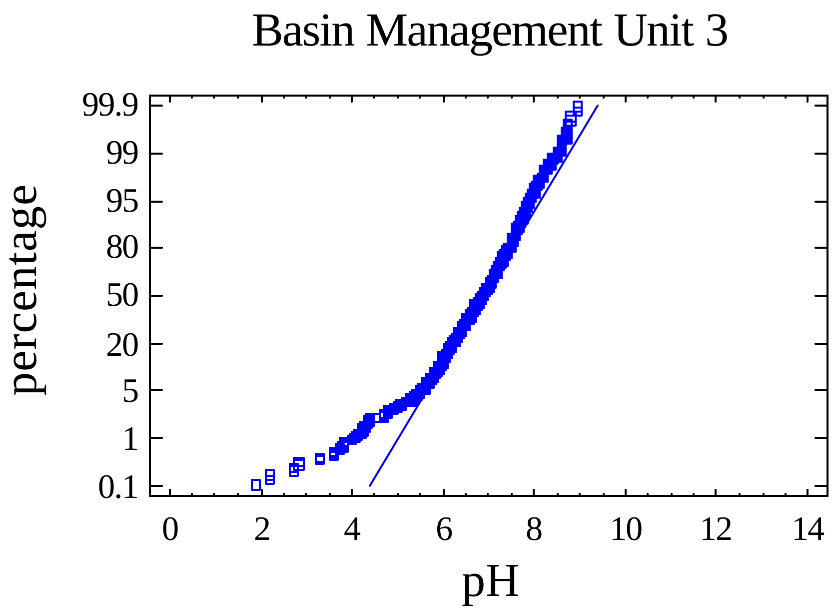

Figure 1. Probability plot of pH values from sites in BMU 3. Measurements follow a normal distribution between values of about 5.5 and 8.5, with a tail to lower values.

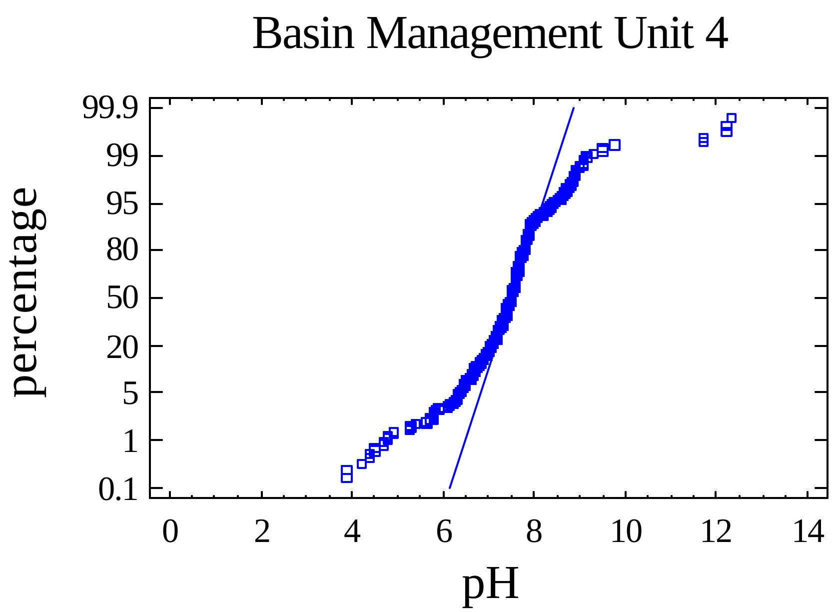

Figure 2. Probability plot of pH values from sites in BMU 4. Measurements follow a normal distribution between values of about 7 and 8, with tails to both higher and lower values.

Box and whisker plots (Figs. 3 and 4) compare median values (vertical line through box), interquartile ranges (pH range encompassed by the box), and outlier values (whiskers extend 1.5 times the IQR from each end of the box; values that fall beyond the whiskers but within 3 times the IQR are plotted as individual squares) in major watersheds (6-digit Hydrologic Cataloging Units) in each BMU. In BMU 3, the greatest range of pH values, as well as the lowest pH values, were found in the Upper Cumberland River Basin which flows through the Eastern Kentucky Coal Field. The central 50 percent of pH values (boxes) are more tightly clustered in the predominantly carbonate Lower Cumberland River Basin and the sandy Jackson Purchase Region (Mayfield and Obion Creek Basins) than in the more lithologically heterogeneous Lower Tennessee and Upper Cumberland River Basins.

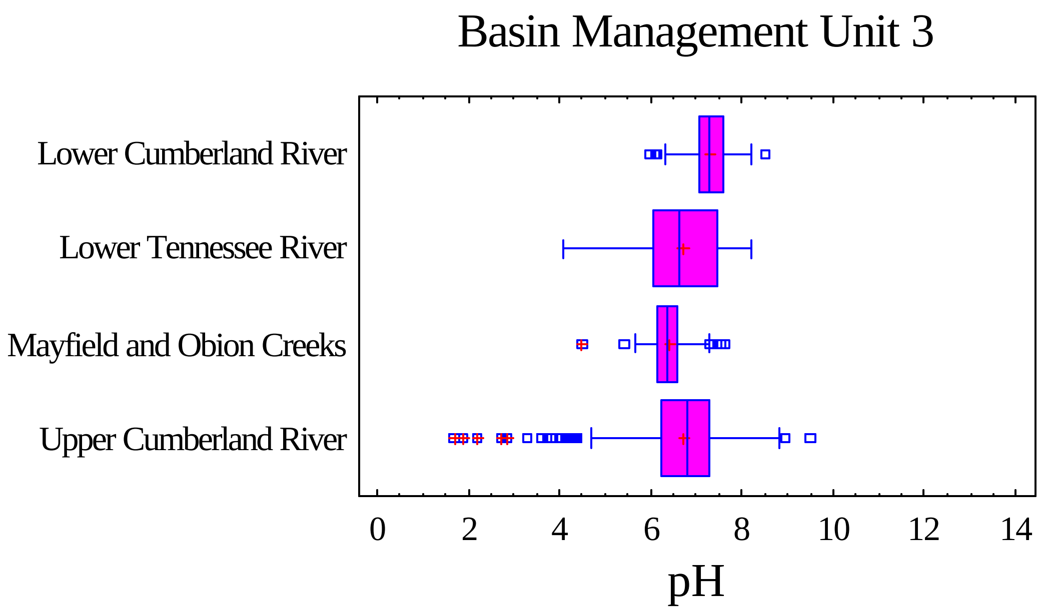

Figure 3. Box and whisker plot of pH data from major watersheds in BMU 3.

In BMU 4 (Fig. 4), samples from the Green River watershed have a greater range of pH values than samples from the Tradewater River watershed. The Green River Basin includes the carbonate terrain of the Eastern and Western Pennyroyal Regions and the sandstone, shale, and coal strata of the Western Kentucky Coal Field, accounting for the range of pH values.

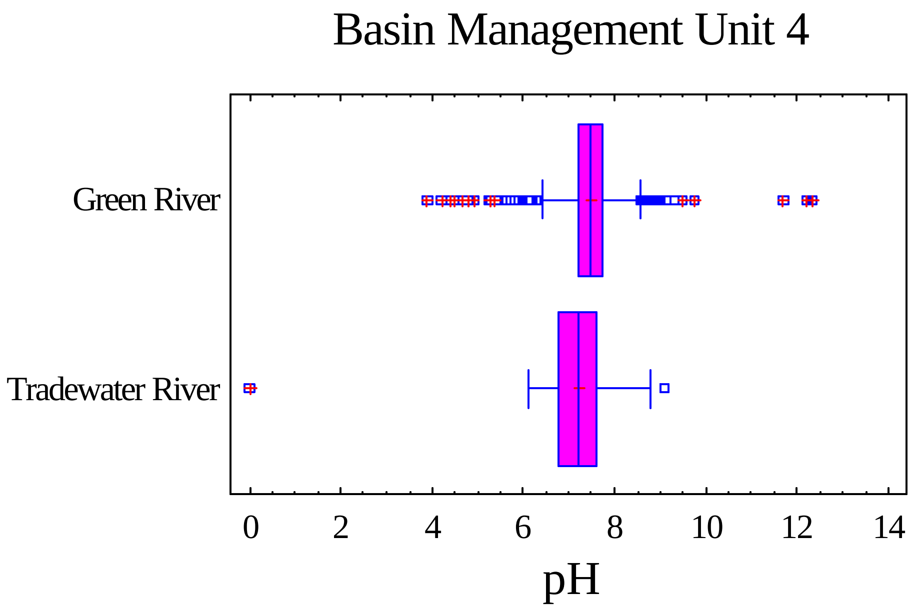

Figure 4. Box and whisker plot of pH data from major watersheds in BMU 4.

Mapping Concentration Ranges

Maps of groundwater quality data show the sample site distribution throughout the state and reveal geologic and geographic influences on concentrations. For clarity, values are grouped into three or four concentration ranges, each represented by a different symbol. With more than four symbols, maps become difficult to interpret. Concentration ranges are chosen to represent maximum contaminant level (MCL) values established for drinking water, recommended levels for various nondomestic uses, or quartile values.

As an example, arsenic concentrations were grouped into three classes: concentrations greater than 0.050 mg/L (the MCL from 1974 to 2002), concentrations less than 0.010 mg/L (the current MCL), and concentrations between these two MCLs (Fig. 5). The map shows that arsenic values greater than 0.010 mg/L are rare in Kentucky and are not preferentially concentrated in any particular geographic region.

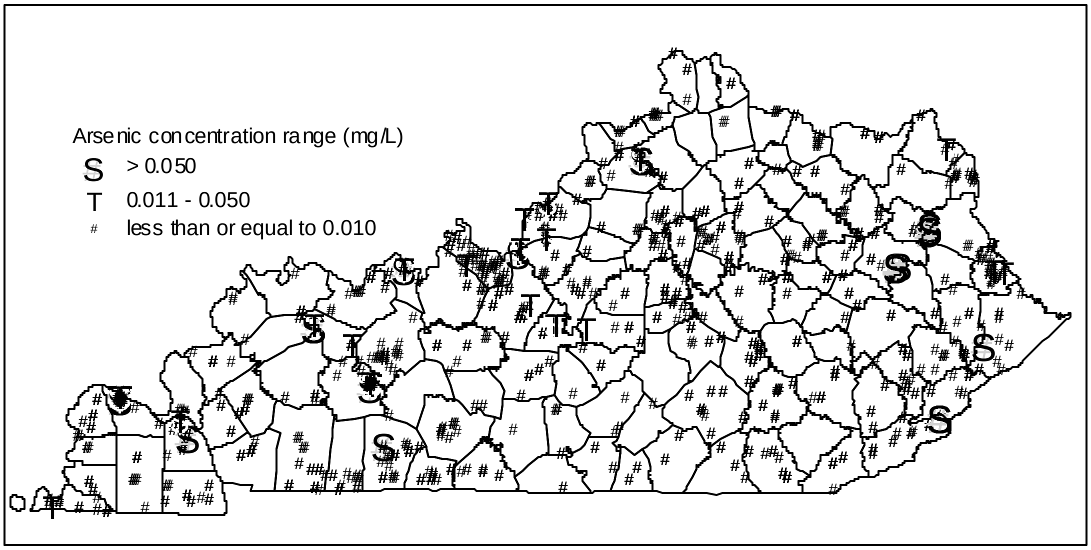

Figure 5. Map of arsenic concentrations in Kentucky groundwater.

Summary

Kentucky groundwater is important for domestic, commercial, agricultural, and industrial water supplies, and groundwater use is increasing. Groundwater is also the major source of water in Kentucky's rivers and streams, and is particularly critical for water supplies and sustaining fragile ecosystems during droughts. Groundwater purity is generally taken for granted; however, groundwater quality is increasingly threatened by urban, industrial, commercial, and agricultural contaminants. To intelligently manage and protect this precious natural resource, current groundwater quality must be assessed and evaluated.

KGS and DOW are working together to collect groundwater quality data, translate analytical data records into useful information, and distribute that information to legislators, regulators, researchers, educators, and the general public by producing data summaries and maps of water quality. To date, maps of nitrate, fluoride, and arsenic have been published, and reports summarizing groundwater quality in major watersheds are being prepared.

Important work remains, however. Sample coverage must be improved before ambient conditions can be determined and both pristine and contaminated areas can be identified. Sampling frequency and the list of analytes must be evaluated to improve efficiency. Important historical water-quality data that exist only in hard copy must be added to the electronic databases. Most important, a regular program of sample collection and analysis, data evaluation, and distribution of groundwater quality information through presentations, publications, and Web sites is needed, and this information must be reviewed and updated regularly.

Most of the ongoing and recently completed groundwater investigations are the result of cooperative efforts between DOW and KGS. These joint efforts allow both organizations to accomplish more than they could separately. Recent work characterizing groundwater quality and circulating the findings has largely been accomplished through the use of nonrecurring funds obtained from a variety of sources. Availability of these funds is decreasing, however. A stable source of recurring funds is needed to continue this important work.

References Cited

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